

# High Electron Mobility Transistor Structures on Sapphire Substrates Using CMOS Compatible Processing Techniques

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System-on-a-chip (SOC) processes are under intense development for high-speed, high frequency transceiver circuitry. As frequencies, data rates, and circuit complexity increases, the need for substrates that enable high-speed analog operation, low-power digital circuitry, and excellent isolation between devices becomes increasingly critical. SiGe/Si modulation doped field effect transistors (MODFETs) with high carrier mobilities are currently under development to meet the active RF device needs. However, as the substrate normally used is Si, the low-to-moderate substrate resistivity causes large losses in the passive elements required for a complete high frequency circuit. These losses are projected to become increasingly troublesome as device frequencies progress to the Ku-band (12 – 18 GHz) and beyond. Relative to Si, the high electrical resistivity of sapphire enables superior performance in passive devices such as inductors, and less cross-talk between devices. The use of silicon-on-sapphire circuitry for low-power, radiation-hard devices is well known. Sapphire is an excellent substrate for high frequency SOC designs because it supports excellent both active and passive RF device performance, as well as low-power digital operations.

We are developing high electron mobility SiGe/Si transistor structures on r-plane sapphire, using either in-situ grown n-MODFET structures or ion-implanted high electron mobility transistor (HEMT) structures. Advantages of the MODFET structures include high electron mobilities at all temperatures (relative to ion-implanted HEMT structures), with mobility continuously improving to cryogenic temperatures. We have measured electron mobilities over 1,200 and 13,000 cm<sup>2</sup>/V-sec at room temperature and 0.25 K, respectively in MODFET structures. The electron carrier densities were 1.6 and 1.33x10<sup>12</sup> cm<sup>-2</sup> at room and liquid helium temperature, respectively, denoting excellent carrier confinement. Shubnikov de-Haas oscillations were observed, thus confirming the 2D nature of the carriers. Conversely, HEMT structures using ion-implanted processing are appealing because they are compatible with existing CMOS processing, and thus would be attractive for complex, highly integrated circuitry. Using this technique, we have observed electron mobilities as high as 900 cm<sup>2</sup>/V-sec at room temperature at a carrier density of 1.3x10<sup>12</sup> cm<sup>-2</sup>. The temperature dependence of mobility for both the MODFET and HEMT structures provides insights into the mechanisms that allow for enhanced electron mobility as well as the processes that limit mobility, and will be presented.

Using the MBE Sb doped structures, transistors with varying source-to-drain distances and gate lengths (1 – 5 μm) were fabricated. Although the design is not optimized, the

initial results are promising. The I-V behavior indicated the saturated drain current region extended over a wide drain voltage range, with knee voltages of approximately 0.5 V and increased leakage starting at voltages slightly higher than 4 V. The saturation drain currents were lower than expected, and reasons for this are under investigation.